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and the
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DESIGN OF AN OUTLET FOR BOX INLET DROP SPILLWAY

by
Charles A. Donnelly
Division of Drainage and Water Control

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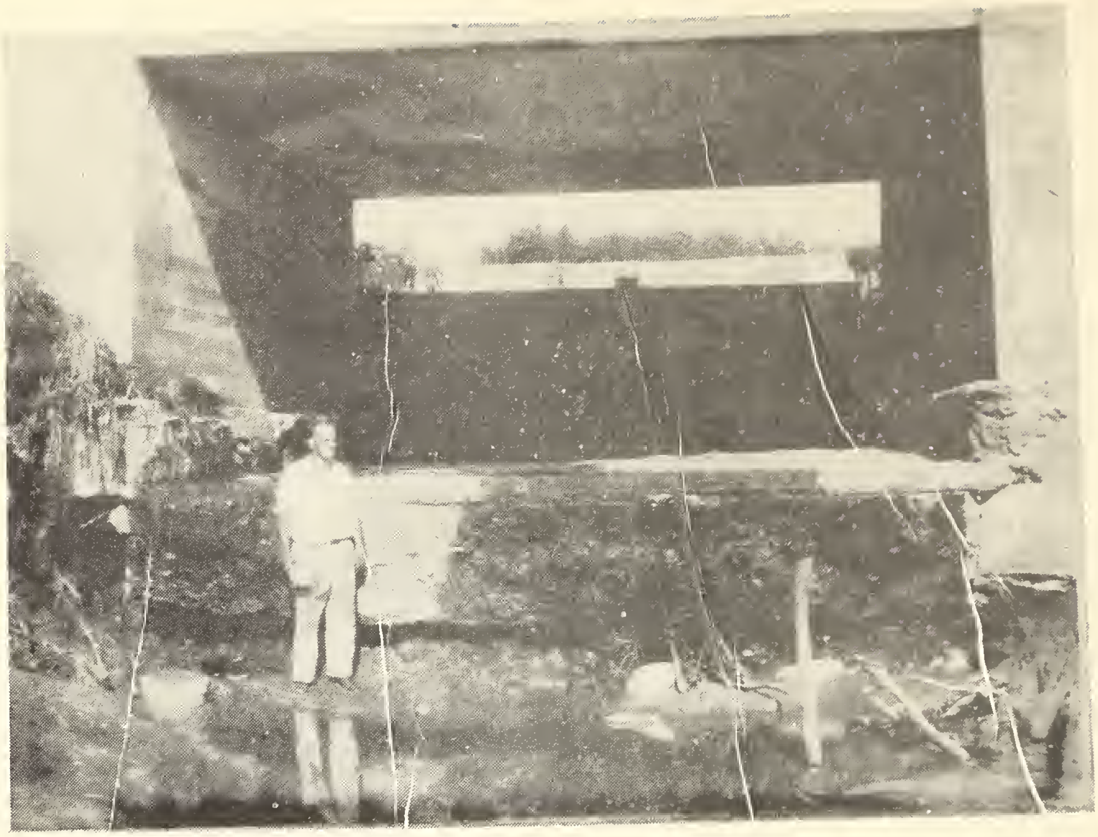
INTRODUCTION

The study of outlets for box-inlet drop spillways was undertaken to develop a universal outlet design for this type of structure. A box-inlet drop spillway may be defined as a rectangular box, open at the top and downstream ends. Water enters the box over the two sides and the upstream end and leaves it through the open downstream end. A headwall and dike opposite the downstream end of the box direct the water to it.

The outlet as designed in the past could more properly be called an "apron," with the floor set at the grade of the downstream channel. The water leaves the apron at a high velocity, causing a horizontal whirling action of the water on each side of the channel. These whirls result in severe scour of the dam fill and the stream bed at the end of the apron. Outlets of this type have failed; two typical failures are shown in figure 1.

Studies of outlets for box-inlet drop spillways were initiated late in 1942 at the request of the Region 3 Engineering Division. A paper entitled "Progress Report on Design of an Outlet Structure for Head Spillways" was prepared late in 1943 and released in 1944 giving rules for the design of an outlet structure. Although this outlet design has a limited range of application, it was released at that time to satisfy the immediate needs of the Operations engineers. The major limitations in this design are: (a) The proportions of the outlet are based on an assumed shape of dam fill, which cannot always be placed as the design requires, rather than on hydraulic criteria, and (b) the flare and width of the outlet are such that they do not fit field conditions at many locations.



(*a*) View of severe erosion occurring below a box-inlet drop spillway near Richland Center, Wis.

(*b*) A view of another failure of a drop spillway near Sparta, Wis. Note the damage to the fill caused by back eddies during high discharge.

FIGURE 1.--Unsatisfactory outlets.

Investigations to develop a more generalized design were resumed late in 1944 and completed in June 1946. The outlet resulting from this design can be used for any size or shape of box-inlet drop spillway discharging any quantity of water.

The tests were performed by the writer at the St. Anthony Falls Hydraulic Laboratory of the University of Minnesota, Minneapolis, Minn. There, the Minnesota Agricultural Experiment Station and the Soil Conservation Service cooperate in solving problems in conservation hydraulics under the direction of Fred W. Blaisdell, project supervisor. M. L. Nichols is Chief of Research of the Soil Conservation Service and Lewis A. Jones, Chief of its Division of Drainage and Water Control, of which the project at Minneapolis is a part.

The constructive criticism of L. G. Straub, director of the St. Anthony Falls Hydraulic Laboratory, and of M. M. Culp, head of the Design and Construction Section of the Region 3 Engineering Division, was especially appreciated and is hereby acknowledged. The assistance and criticisms of Fred W. Blaisdell, E. Clare Gosslin, and the Washington editorial staff in the writing and editing of this report are also appreciated.

THE PROBLEM

The study of box-inlet drop-spillway outlets was undertaken to determine the proportions of an outlet that could be used with any size spillway and in all types and sizes of gully. Since most of the structures built by the Soil Conservation Service are small, individual model studies of each structure to determine the best design could not be justified. However, when the cost can be distributed over a large number of structures, model studies become economical. It was for this reason that a generalized study of outlets for box-inlet drop spillways was made.

LABORATORY FACILITIES

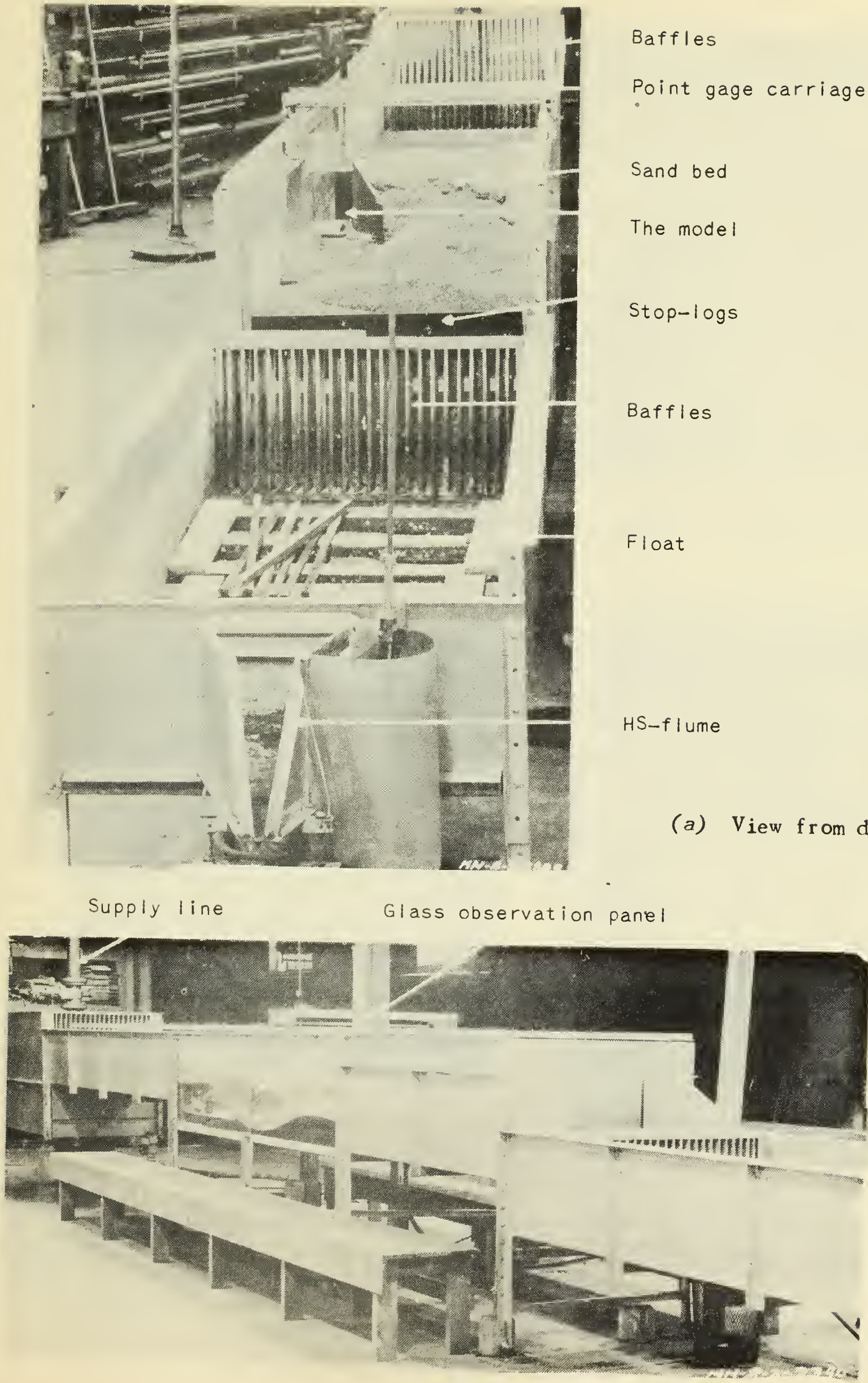
The water used for the experiments was obtained from the main laboratory supply channel through a 4-inch pipe line, and the discharge was controlled by a gate valve. The rate of flow through the model was determined by means of a calibrated 1-foot type HS-flume located

downstream from the model. The tests were conducted in the channel shown in figure 2. The channel was 3 feet wide. The entrance box was followed by a 10-foot approach section 18 inches deep. The test section was 13 feet long by 24 inches deep and was provided with an 8-foot glass observation panel at one side. A point gage was attached to a carriage which ran on rollers along the top of the channel in such a manner that levels anywhere in the approach channel and in the test section could be readily obtained. This gage was used in setting the models to the correct elevations and in determining the levels of the water surface and the sand bed. The final section of the channel was 10 feet long by 18 inches deep and served as an approach to the HS-flume. Water discharged from the HS-flume into the laboratory waste channels which lead to the river below the falls.

THE MODELS

All models were halved (split along their centerlines) and set against the glass panel in the channel as shown in figure 2(a). With this half-model arrangement and the glass panel it was possible to observe the stilling action and the bed scour while the test was in progress. The rough water surface prevents this where full models are used. Previous experiments on culvert outlets have shown that identical results can be obtained from either full or half models.

Near the conclusion of the box-inlet drop-spillway-outlet tests this method of conducting tests was checked on a full model, half the size of the half models. A view of this model is shown in figure 3(c). After the full model had been tested, a lucite plate was placed at the centerline of the structure to give, in effect, two half models as shown in figure 3(d) and the test repeated. The results of the tests are shown in figure 3. Confetti has been sprinkled on the water surface of the flow photographs, figures 3(a) and (b), to show the stream lines. A careful comparison of the two photographs will show that the flow patterns are identical. The scour patterns are compared in figures 3(c) and (d). A small disagreement in scour patterns will be noted between the two halves of figure 3(d). This is probably due to the fact that the upstream dividing wall was not placed so as to separate the flow into exactly equal parts. However, the bed slopes are small and a considerable displacement in plan position of the contours represents only small differences between the depths on either side of the centerline. It can be



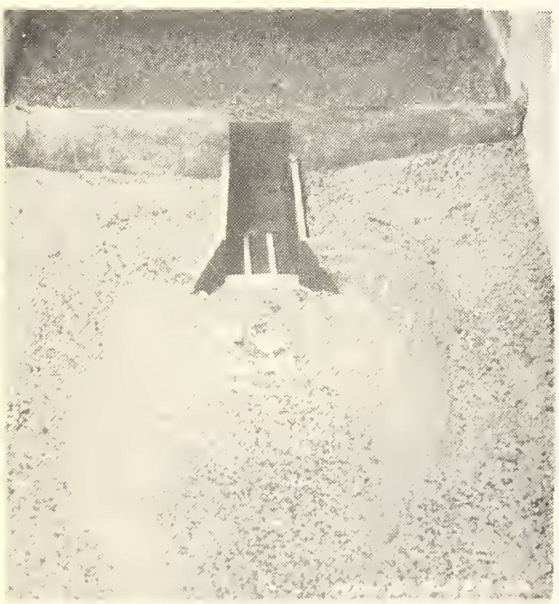
(a) View from downstream.

(b) Oblique view.

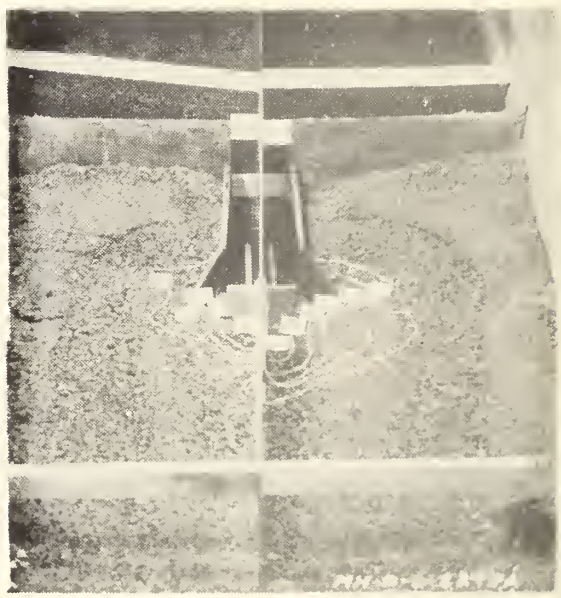
FIGURE 2.--Test channel.

(*a*) Flow pattern for full model.

(*b*) Flow pattern for half model.



(*c*) Scour pattern for full model.



(*d*) Scour pattern for half model.

FIGURE 3.--Comparison of results obtained on full and half models.

seen that the average scour pattern for the half model is identical, within the limits of precision of this experiment, with the results obtained on the full model.

The box-drop inlet spillway was made of 1-inch pine while the outlet proper was constructed of 3/8-inch waterproof plywood. With this use of lumber, any required changes were made with very little effort.

Ordinary concrete sand passing an 8-mesh screen was used for the stream bed downstream from the outlet; the erosion of the sand bed was used as a measure of the efficiency of the outlet.

TEST METHODS

In each experiment the control valve was opened to give the desired discharge. The tailwater level was next adjusted by means of stop-logs located at the downstream end of the channel. The stream bed was then overfilled with sand, and the water was run over it until little or no sand movement occurred. For the first tests 30-minute runs were satisfactory. As the outlet was improved, the rate of scour was greatly decreased, and it became necessary to increase the length of run to 4 hours in order to bring out significant differences in the scour pattern.

At the conclusion of each test the control valve was closed and the model allowed to drain. The water level in the outlet was measured at intervals during the drainage process by means of a point gage. White-wool yarn was placed on the water line at 0.05-foot intervals to define the contours. The stream bed was then photographed to record the scour. Zero elevation was assumed to be the level of the outlet floor.

CRITICAL DEPTH

The proportions of the outlet described herein are based on the critical depth of flow. Since the derivation of the critical depth equation and its significance can be found in any standard text on hydraulics, it is not derived here. However, the equations used in this report are defined on the next page.

The equation for the critical depth in the straight section of the outlet, d_c, is

$$d_c = \sqrt[3]{\frac{(Q/W)^2}{g}} \quad \text{- - - - - - - - - - - - - - - -} \quad (1)$$

where Q is the discharge, W the width of the straight section, and g the acceleration due to gravity.

At the end of the stilling basin the equation becomes

$$d_{ce} = \sqrt[3]{\frac{(Q/W_e)^2}{g}} \quad \text{- - - - - - - - - - - - - -} \quad (2)$$

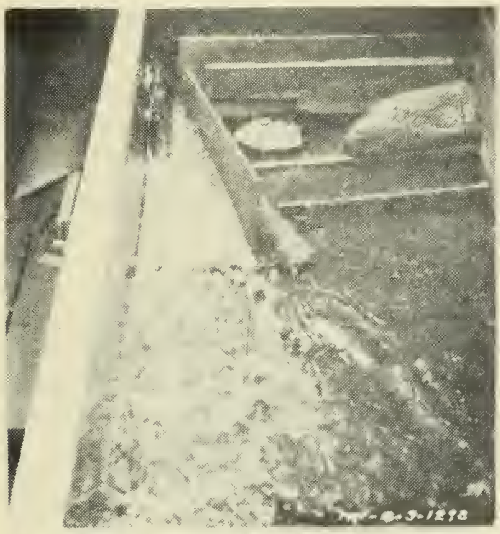
where d_{ce} is the critical depth and W_e the width.

TEST RESULTS

The first tests on the box-inlet drop-spillway outlet were exploratory in nature. From them the general form of the outlet evolved. After the form of the outlet had been established, tests were made to determine the design equations and the ranges of their application. In the following pages each element entering into the design will be discussed in a manner that will permit the reader to verify, independently, the adequacy of the design criteria.

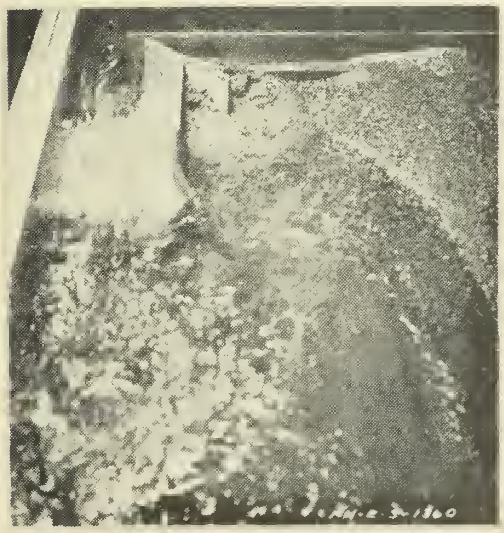
Straight Section

The form on the outlet was determined largely by the manner in which the water left the box inlet. For this reason it is pertinent to describe the outflow briefly. The water flowing over the side of the box inlet springs clear of the sidewall, creating a space between and under the nappe and the sidewall. This space is filled with water rolling about a horizontal axis which spirals out from under the nappe at the exit to the drop inlet. The roller may be seen in figure 4(a). Where the rollers strike the floor of the outlet, they spread out, creating an impact wave against and high velocities along the sidewalls. The wave is fairly prominent in figure 4(b). The uneven velocity distribution at the end of the outlet gives rise to eddies in the downstream channel and results in very poor scour patterns.

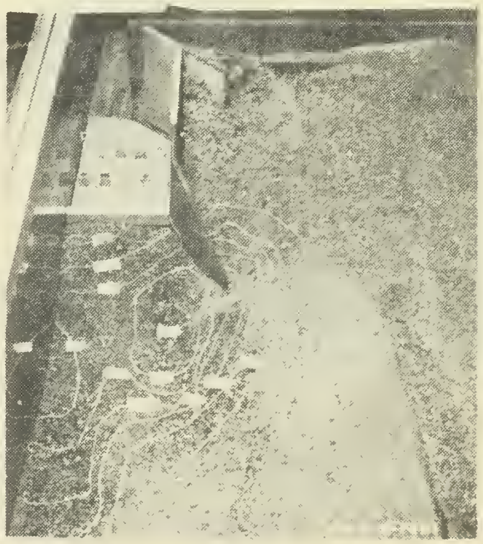


(a) Sidewall flare 3:1.

FIGURE 4.--Preliminary forms of the outlet.



(b) Sidewall flared 1:1 and then parallel to centerline.



(c) Scour pattern.

In figure 4(a) it may be noted that where the sidewall flare starts at the end of the spillway box, the crest of the wave and the maximum velocity occur along the sidewalls. The flare of the sidewall in this figure is 3:1. In figure 4(b) it may be seen that where the sidewall is set first at a flare of 1:1 for a distance equal to one-half the box width and is then extended parallel to the outlet centerline, a high wave is formed at the intersection of the flared and parallel sections, and the velocity is very low at the centerline. **Figure** 4(c) shows the resulting scour pattern for the flow shown in figure 4(b). In both of the models shown in figure 4 various combinations of baffles, angular sills, cross sills, longitudinal sills, and end sills were made in an effort to obtain a satisfactory flow pattern, but no combination was successful.

After running tests with several variations of sidewall design, it was found that if a straight section (one having parallel sidewalls) equal to the box inlet in width were used between the box inlet and the outlet proper, the roller was broken up, the flow distribution improved, better use made of the tailwater, and the resulting scour pattern improved. Figure 5 shows the flow conditions where this straight section was used.

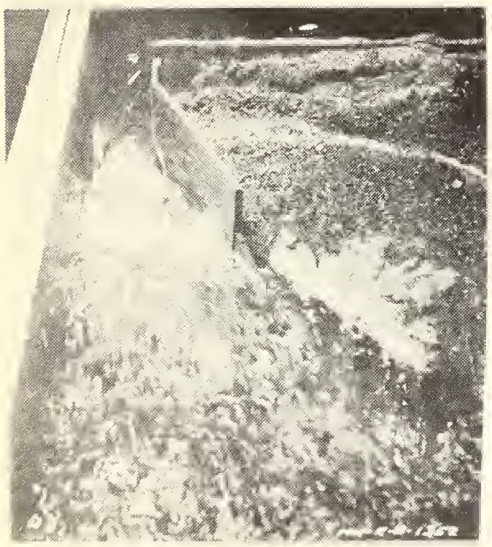


FIGURE 5.--Outlet with straight section.

In order to develop a design for the straight section of the outlet and to produce comparable results, it was necessary, when the remaining design factors were unknown, to keep the tailwater depth constant. As a result of preliminary tests, $1.5d_{ce}$ was the tentative depth selected for this series of experiments. The end and longitudinal sills were $W/8$ high, the wingwalls were triangular in shape with a top slope of 45 degrees and were set at an angle of 45 degrees from the outlet centerline. Various box lengths ranging from $B/W = 0.25$ to 2.0 were used.

The basin length was held constant and the length of the straight section varied from run to run. The rate of flow through the structure was adjusted to the maximum that gave good flow distribution over the end sill. The proper amount of tailwater was then set, the stream bed filled, and water run over it to obtain the scour pattern. In each additional run the straight section was shortened and the testing conducted in the manner described above until the straight section became so short that it no longer functioned.

The data obtained from these tests are plotted in figure 6, using as coordinates $(L_s/d_c) - 1$ and B/W. The selection of the coordinates was by trial and error. The inclusion of B/W is a result of the flow pattern as described at the beginning of this section--for long box inlets less distance is required to obtain good flow distribution in the outlet. The curve drawn through the plotted data has the equation

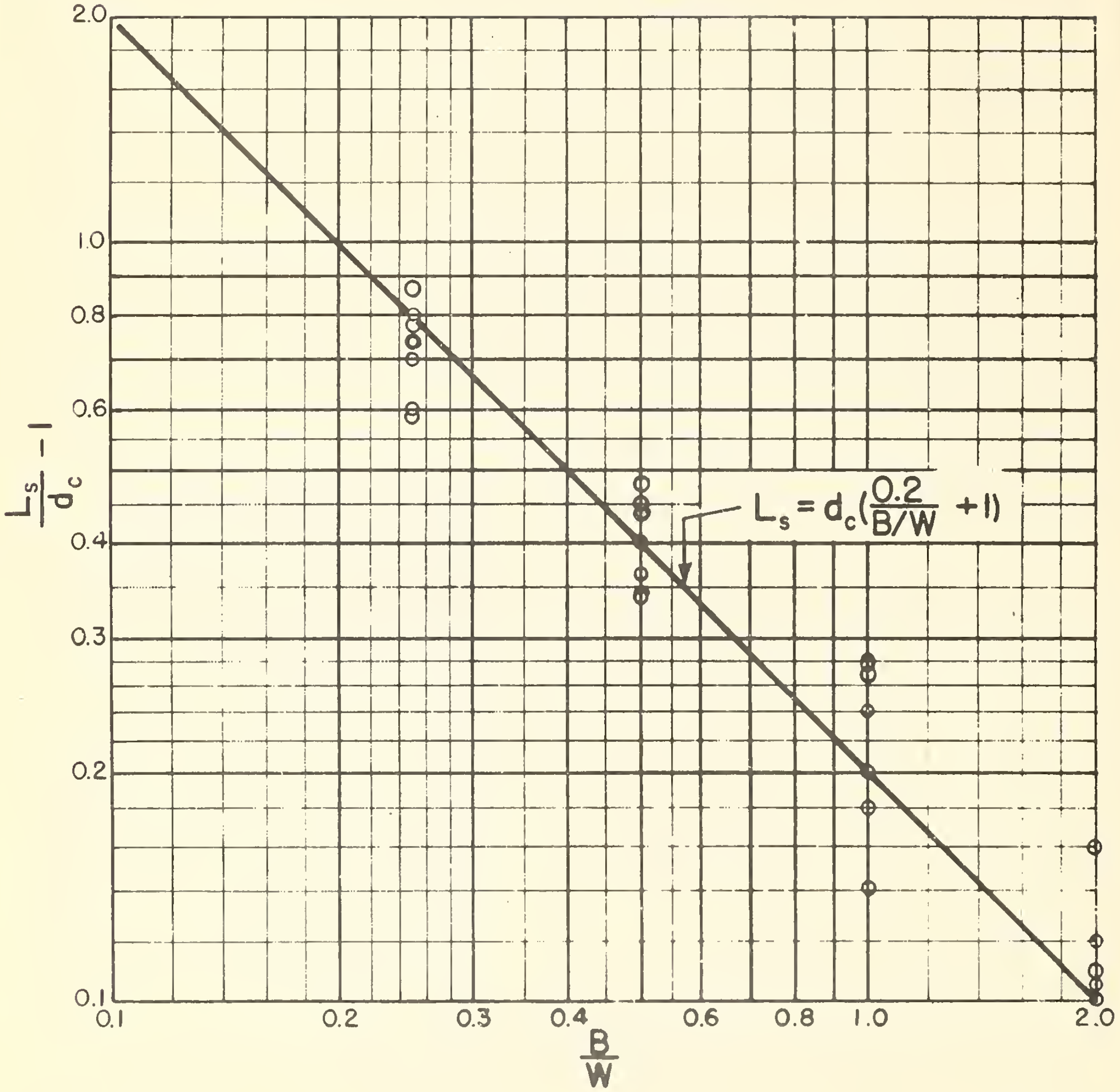
$$L_s = d_c\left(\frac{0.2}{B/W} + 1\right). \qquad (3)$$

The points are scattered in figure 6 because of the manner in which the data were obtained. The quantity of water which gave good flow conditions over the end sill was determined only by visual observation. Therefore, for the same length of straight section, it is possible that two or more flows could be equally acceptable. Check tests on this portion of the outlet and tests on the other parts show that Equation (3) satisfactorily defines the minimum length of basin that can be used. However, the straight section can be any length greater than that given by Equation (3) and still function properly.

It will be noticed that B/W appears in the denominator of the equation. As B/W approaches zero, the minimum length of the straight section therefore becomes infinite. This seems unreasonable. Equation (3) is valid and should be used only for values of B/W equal to or greater than 0.25--the minimum covered by the tests. It is not intended that the outlet described here be used for straight overfalls such as would be the case if $B/W = 0$. The form of Equation (3), therefore, serves as a means of preventing its use where other types of outlet would be more economical.

Stilling Basin Sidewall Flare

Since the outlet studied here will be used under a variety of field conditions, it is desirable that the width of the outlet be varied over as wide a range as possible. This can be accomplished by flaring the walls of the stilling basin. Therefore, a series of tests was run to determine if different sidewall flares could be used. Results showed that the sidewalls could be parallel or flared up to 2 longitudinal to 1 transverse. However, if the sidewall flare is greater than 2:1, the water will not spread out rapidly enough to follow the sidewalls, the stream



LENGTH OF STRAIGHT SECTION

will be concentrated at the center of the stilling basin, whirls will develop between the stream and the walls, and the greater flare becomes uneconomical.

Tailwater Depth

Because the velocity of the water in the box-inlet drop-spillway outlet was low (slightly greater than the critical velocity), it was thought that most of the energy would be dissipated by the tailwater, thereby eliminating the necessity for sills or other types of energy dissipator. It was also desirable to design a model where any excavation below the stream-bed level might be eliminated.

To determine the best tailwater depth, spillway ratios of length to width, B/W, of 0.5, 1.0, 1.5, and 2.0 were tested; the depth ratio, D/W, was 1, and the length of the straight section of the outlet was based on the design formula. The height of the end and longitudinal sills was $W/8$, and the wingwall was set at a 45-degree angle from the centerline and cut on a 45-degree top slope. In each run various depths of tailwater were tried to find the minimum depth that would keep a hydraulic jump in the basin.

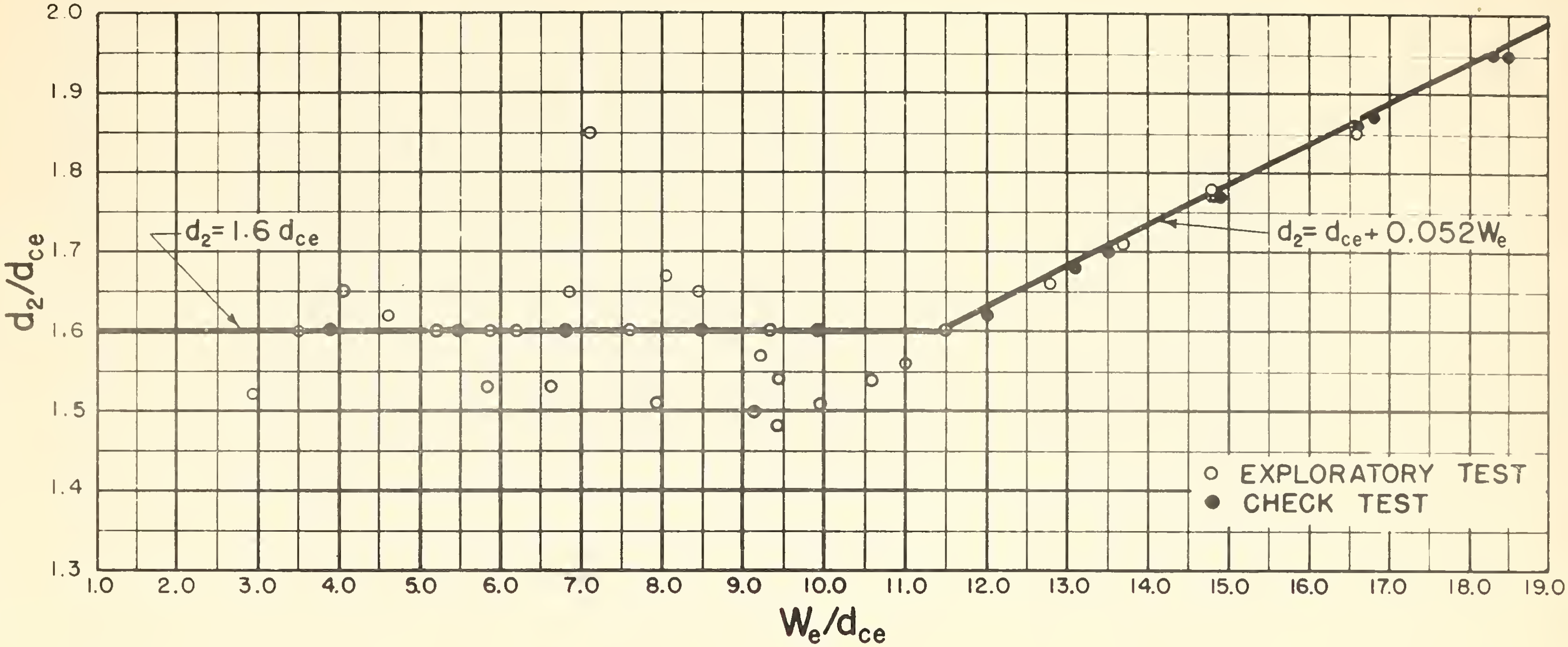
When the preliminary results of the tests were computed, there seemed to be a definite relationship between the critical depth at the end of the basin, d_{ce}, and the minimum required tailwater depth, d_2, measured above the basin floor. In figure 7 d_2/d_{ce} is plotted against W_e/d_{ce}. The curves have the equations

$$d_2 = d_{ce} + 0.052W_e \text{ - - - - - - - - - - - - - } (4)$$

and

$$d_2 = 1.6d_{ce} \text{ - - - - - - - - - - - - - - - - - - } (5)$$

where W_e is the outlet width at the end of the stilling basin. Equation (5) can be used only when the ratio of W_e/d_{ce} is less than 11.5. Equation (4) is used at higher ratios of W_e/d_{ce} because the tests showed that dead or nearly dead water exists along the sidewalls near the end of the basin when this ratio is greater than 11.5. That portion of the outlet occupied by dead water is obviously not being used to dissipate energy, and the outlet would operate just as well if it were



DETERMINATION OF TAILWATER DEPTH

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Figure 7

eliminated. Therefore, the end width of the outlet should not exceed $11.5d_{ce}$. Satisfactory results can be obtained with wider basins if the tailwater depth is computed from Equation (4), but the wider basins make inefficient use of the outlet and will likely be more expensive than a basin with a narrower outlet width.

Check tests using tailwater depths computed from Equations (4) and (5) proved that the equations were satisfactory. Another series of tests with a tailwater higher than the designed d_2 gave as good or better scour patterns than the design.

Stilling Basin Length

Because the width of the outlet controls the required tailwater depth and the tailwater depth determines the position of the hydraulic jump in the basin, it is reasonable to expect that the length of the stilling basin would not be a critical factor in the design of the outlet for a box-inlet drop spillway as long as it is greater than a certain minimum.

With this in mind, tests were run to determine the minimum length of the stilling basin with box inlets having shape ratios of $B/W = 2.0$, 1.5, 1.0, and 0.5, a depth ratio of $W/D = 1$, the design straight section and tailwater depth, end and longitudinal sills $W/8$ high, and wingwalls set at a 45-degree angle and cut on a 45-degree slope. Approximately the same quantity of water was used for all runs in this series. The basin length for the initial test was very long and was reduced gradually until at last the basin was so short that it had no effect at all on the stream flow.

Observation showed that for the short box inlets the jet shoots out at a high level and takes a relatively greater distance to level out than for the longer boxes, and that the basin length must be proportionately greater for the same discharge. Where the box inlet is long, the water shoots out from the bottom of the box and levels out in a relatively short distance, thereby requiring less basin length.

The data obtained during these tests may be found in table 1. A comparison of the values listed in the column showing $\frac{L_B}{L} \times \frac{B}{W}$ with the notes shows that this ratio must be 0.50 or greater if the basin is

TABLE 1.--*Minimum length of basin*

$W = 0.667$ ft., $d_2 = 1.60 d_{ce}$

Run No.	Q c.f.s.	$\frac{B}{W}$	$\frac{D}{W}$	L ft.	L_s ft.	L_B ft.	$\frac{L_B}{W} \times \frac{B}{W}$	Scour: Maximum[1] ft.	Scour: Distance[2] ft.	Notes
					(a) Length of run = 1/2 hour.					
163	0.700	1.00	1.00	2.00	0.410	1.160	0.58	0.07	0.7	b
164	.700	1.00	1.00	2.00	.410	1.000	.50	.07	.7	b
165	.700	1.00	1.00	2.00	.410	.667	.34	.07	.7	a
166	.700	1.00	1.00	2.00	.410	.583	.29	.07	.5	a
182	.700	1.00	1.00	2.00	.410	1.160	.58	.12	.7	b
183	1.130	2.00	1.00	3.33	.410	1.160	.70	.07	.6	b
184	1.130	2.00	1.00	3.33	.410	1.000	.60	.07	.7	b
185	.824	1.50	1.00	2.66	.410	1.000	.56	.05	.5	b
186	.700	1.00	1.00	2.00	.410	1.000	.50	.02	.4	b
187	.700	1.00	1.00	2.00	.410	.830	.42	.15	.6	a
188	.824	1.50	1.00	2.66	.410	.830	.47	.15	.7	a
					(b) Length of run = 4 hours.					
358	.530	1.00	.50	2.00	.324	1.000	.50	.07	.8	b
359	.810	2.00	.50	3.33	1.330	.830	.50	.06	.6	b
360	.800	2.00	1.00	3.33	.390	.830	.50	.07	1.0	b
361	.305	1.00	.25	2.00	.224	1.000	.50	.03	.5	b
363	.530	1.00	.50	2.00	.324	1.200	.60	.08	.7	b
365	.810	2.00	.50	3.33	.396	.830	.50	.05	.6	b
369	.345	.50	.25	1.33	.288	1.330	.50	.03	.5	b
371	.305	1.00	.25	2.00	.224	1.200	.60	.06	.7	b
373	.328	2.00	.25	3.33	.218	1.200	.72	.03	.5	b
374	.400	1.00	.25	2.00	.268	1.200	.60	.05	.2	b
375	.405	2.00	.25	3.33	.247	.830	.50	.02	.4	b
386	.750	1.50	1.00	2.66	.390	.880	.55	.07	.7	b

Notes: [1]Below floor of stilling basin.
[2]From end of stilling basin.

a. Basin too short. Jet lands close to end sill.
b. Basin length satisfactory.

to have sufficient length. Here L_B is the stilling basin length and L the crest length of the box inlet. The equation for the minimum length of the stilling basin may be written

$$L_B = \frac{L}{2B/W} \text{. - - - - - - - - - - - - - - - - - - (6)}$$

Lengths greater than this may be used with complete assurance that the outlet will function satisfactorily, but lesser lengths should never be used.

It will be noted that B/W is in the denominator of Equation (6). When B/W = 0, this requires an infinite length of stilling basin, which seems unreasonable. The comments made on this point when discussing Equation (3) also apply to Equation (6).

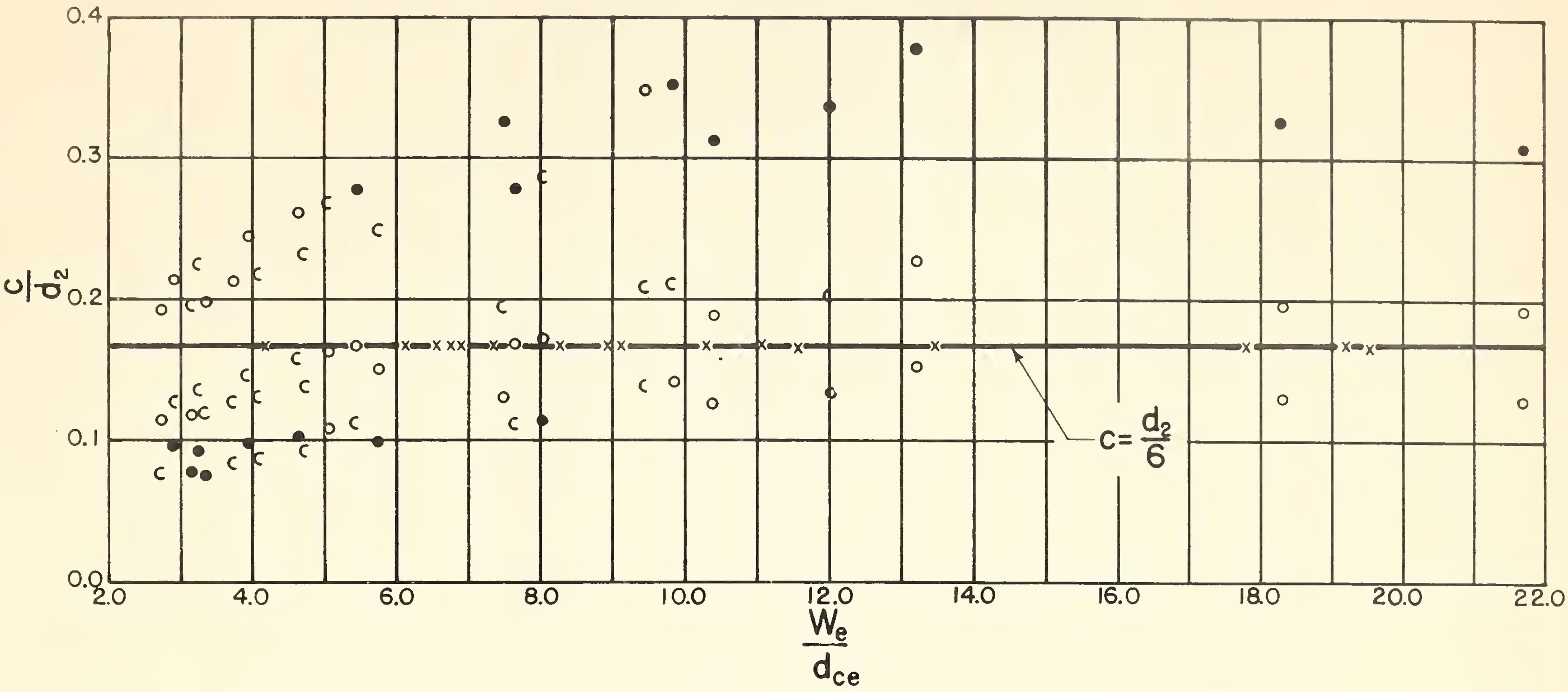
End and Longitudinal Sills

It was found necessary to provide the stilling basin with both end and longitudinal sills. These two types of sill serve very different purposes: The end sill throws the stream upward as it leaves the basin, prevents scour close to the basin exit, and creates a horizontal roller under the deflected stream whose velocity direction is upstream at the bed, thus actually bringing material upstream and depositing it at the end of the basin; the longitudinal sills assist in the distribution of the flow across the stilling basin, prevent high velocities at the sides of the basin, and reduce the scour at the end of the basin and the erosion of the stream banks.

Figure 8, where c/d_2 is plotted against W_e/d_{ce}, shows the method of arriving at a suitable sill height. The resulting points, denoting very good and good end sill heights, are scattered, but it was possible to draw a curve through them. From this curve the equation

$$c = d_2/6 \text{ - (7)}$$

is derived. Check tests proved this equation to be very satisfactory.



HEIGHT OF END SILL

o VERY GOOD c GOOD • POOR x CHECK TEST

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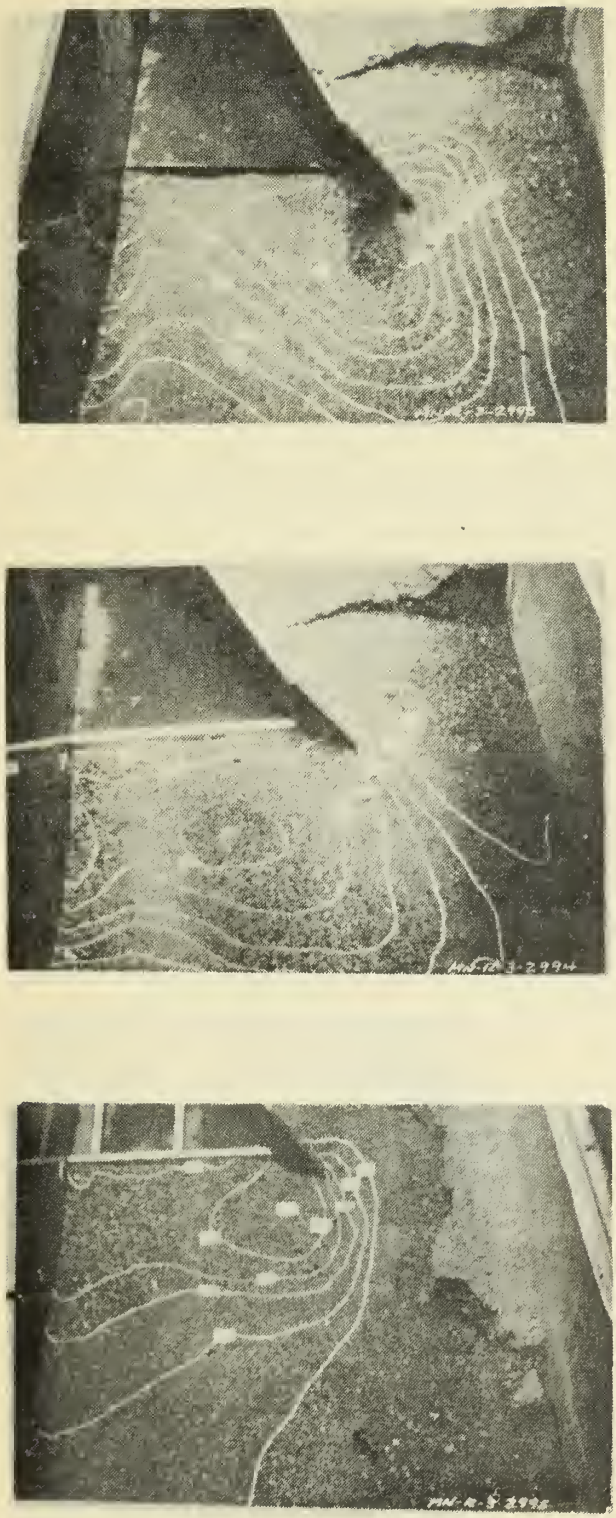
Figure 8



(a) This model has no end or longitudinal sills. The scour is deep and the scour pattern is extremely poor.

(b) In this model an end sill has been added. Note that there is not as much erosion as there is in *(a)*, but the scour pattern is still not satisfactory.

(c) A view of the scour pattern of a design model. Note that there is far less erosion than is pictured in *(a)* and *(b)*, particularly at the side of the channel.

FIGURE 9.--Effect of sills on scour pattern.

When the end sill is too high, the jet leaving the basin jumps over the sill and lands some distance out from the end of the basin, causing severe erosion at that particular location. On the other hand, when the end sill is too low, the water leaving the basin causes the same severe erosion, but it occurs very near the end of the basin.

Figure 9(a) (p. 19) is a view of the model without end or longitudinal sills. Note the severe damage to the dam fill, stream bank near the wingwalls, and at the end of the basin floor. Figure 9(b) shows that even with the addition of an end sill the erosion is still severe, particularly on the stream banks. However, there is considerable reduction in the scour at the end of the basin and in the maximum scour depth. In figure 9(c) where both end and longitudinal sills are used, it will be noted that there is a further reduction in the depth of scour, little scour at the end of the basin, and the stream-bank scour has been reduced to a tolerable amount.

Several different heights of the longitudinal sill were tried. It was found that the height which appeared to be the most satisfactory was the same as that for the end sills.

The longitudinal sills should start at the outlet end of the box-inlet drop spillway and extend to the end sill. Where the basin sidewalls are parallel, longitudinal sills may be omitted. Tests showed that where W_e is less than 2.5W, only two sills are needed. These should be placed from W/6 to W/4 from each side of the centerline, as shown in figure 10(a). Where W_e is greater than 2.5W, two additional

(a) Two sills are needed when W_e is less than 2.5W.

(b) Four sills are needed when W_e is greater than 2.5W.

FIGURE 10.--Location of longitudinal sills.

sills are needed. These should be placed midway between the center sills and the sidewall at the downstream end of the stilling basin. This is illustrated in figure 10(b), page 20.

Sidewall Height

The sidewall height as given here is the height at the end of the stilling basin necessary to keep the water from overtopping the sidewalls and eroding the dam fill. Preliminary study of the data and photographs resulted in the derivation of the equation $(5/4)d_2$ as a satisfactory height. However, when tests were run to check this equation, it was discovered that the height was not great enough to prevent all water from splashing over the walls. When the wall height at the end of the basin was raised to $(4/3)d_2$, no overtopping occurred. The height of the stilling basin sidewalls at the end of the stilling basin should therefore be

$$\frac{4}{3}d_2 \quad \text{- -} \quad (8)$$

or greater.

Wingwalls

The usual function of the wingwall is to hold the toe of the dam in place. In the past, rectangular-shaped wingwalls were set at right angles to the outlet centerline. It was originally believed that this type of wingwall would prevent the eddies created at the sides of the channel from eroding the dam fill. However, many outlets with this type of wingwall have performed poorly. Figure 1(a) shows a typical failure of an outlet with a rectangular-shaped wingwall. Figure 11 is also an illustration of severe erosion of the dam when this type of wingwall is used.

The preliminary tests showed that the rectangular wingwall was unsatisfactory. In connection with other studies a few tests had been run using a wingwall with a 45-degree top slope and placed at a 45-degree angle from the outlet centerline. This type of wingwall proved to be more satisfactory for the box-inlet drop-spillway outlet than the rectangular wall set at a 90-degree angle, and it was used for all tests on

other parts of the outlet. After the proportions of the outlet had been

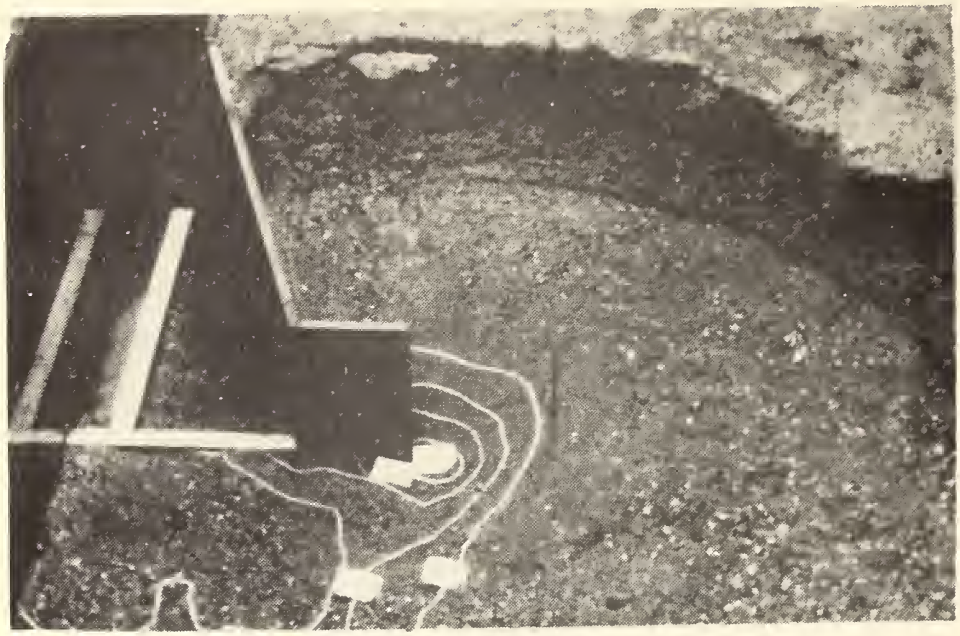
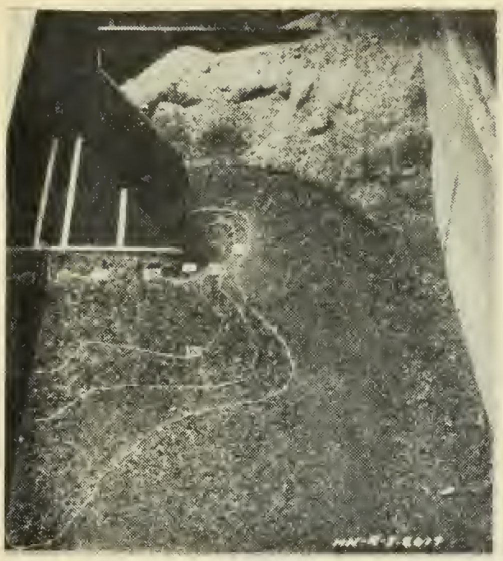


FIGURE 11.--Rectangular-shaped wingwall and severe erosion of fill and at the end of the wingwall.

determined, the wingwalls were subjected to further study. For these tests the design equations already developed were used to determine the proportions of the outlet. Many different wingwall arrangements were tried. Several of the unsatisfactory arrangements and the resulting scour patterns are shown in figure 12. None of the arrangements gave scour patterns that were an improvement over those obtained with the triangular wingwalls. However, it appeared that improvements in the scour patterns could be obtained if the triangular wingwall position or top slope were changed. These tests made to determine the optimum magnitude of these variables are listed in table 2.

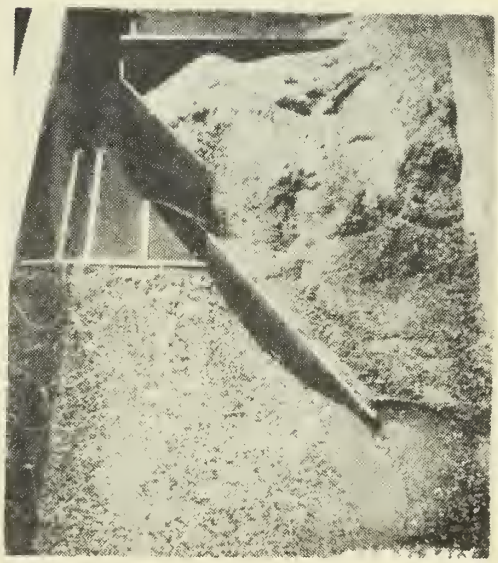
Slight scour may occur near the wingwalls, as a result of the eddies along the side of the channel, or at the centerline of the channel. The magnitude and location of the maximum scour depth are given in table 2. In no case was the scour sufficient to endanger the outlet or cause undue concern. In this regard it should be remembered that the recorded scour depth is the maximum to be expected during the life of the structure.



(a) No wingwall.

(b) Double wingwall.

(c) Basin sidewall extended and cut on fill slope.



(d) Extended basin sidewall.

FIGURE 12.--Poor wingwalls.

TABLE 2.--*Wingwall position and top slope*

W = 0.667 ft., D = 0.667 ft., $d_2 = 1.60d_{ce}$, length of run = 4 hours.

Run No.	Q c.f.s.	B ft.	L_e ft.	L_B ft.	W_e ft.	Wingwall		Maximum scour[3]	
						Position[1] degrees	Top slope[2] degrees	Near wingwall ft.	Near centerline ft.
240	1.28	1.000	0.550	1.2	1.86	60	30	0.09	
241						45	30	.13	
242						30	30	.10	
243						60	37.5	.06	
244						45	37.5	.06	
245						30	37.5		0.03
246						30	45		.07
247						45	45	.03	
248						80	45		.05
249						30	33.5	.05	
250						45	33.5	.10	
251						60	33.5	.04	
252	1.28	1.000	.550	1.2	1.06	30	30	.07	
253						45	30	.05	
254						60	30	.02	
255						30	37.5	.07	
256						45	37.5	.03	
257						60	37.5	.00	
258						30	45	.02	
259						45	45	+.01	
260						60	45	+.02	
261	1.04	.687	.508	1.2	1.46	60	45		.03
262						45	45		.12
263						30	45		.07
264						60	37.5		.05
265						45	37.5		.07
266						30	37.5		.12
267						45	[4]00		.13
268						45	30		.07
269	1.13	1.333	.493	1.2	1.46	45	45	.12	
270						45	37.5	.07	
271						30	37.5		.07
272						30	37.5	-	.08
273						60	37.5	.04	
274						60	30	.03	
275						60	45	+.02	
276						45	45	.02	
277	.80	1.333	.391	1.1	1.03	60	37.5	.05	
278						45	37.5		.05
279						30	37.5		.07
280						60	45		.05
281						45	45		.07
282						30	45	.07	.07
283						60	30		.07
284						45	30	.07	.07
285	.69	1.000	.360	1.1	1.03	60	37.5		.04
286						45	37.5		.03
287						30	37.5		.02
288						60	45		.02
289						45	45		.02
290						30	45		.02
291						60	30	.02	
292						45	30		.02
293						30	30		.02
294	.56	.667	.336	1.1	1.03	30	30		.07
295						45	30		.04
296						60	30	.04	
297						60	45		.02
298						45	45		.04
299						30	45	.03	.03
300						60	37.5		.03
301						45	37.5		.03
302						30	37.5	.03	.03

[1]Angle from centerline.
[2]Angle from horizontal.
[3]Below floor of stilling basin.
[4]Rectangular wingwall; top horizontal.

The choice of the best wingwall position and top slope was difficult to make. Several locations and top slopes were almost identical in performance. However, a thorough study of the data listed in table 2 shows that the wingwall having a top slope of 45 degrees and set at an angle of 60 degrees from the outlet centerline has a slight edge over the others. With this type of wingwall there was very little bank erosion and none at all in back of the wingwall where the fill material rested at its angle of repose, as can be observed in figures 9(c) and 13.

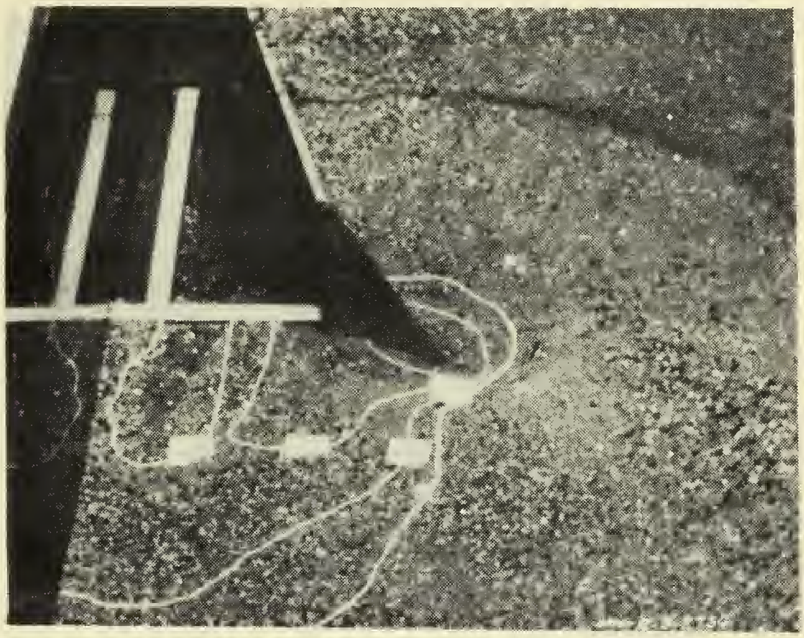


FIGURE 13.--Wingwall with 45-degree top slope and set at a 60-degree angle from the centerline.

Depth of Box

In testing the outlet for box-inlet drop spillways, the depth of the box was not ignored; it was considered in each step of the testing program. However, it will be noted that the depth did not enter into any of the design equations. It is believed that this is due to the manner in which the water flowed through the box inlet. The flow in the box was very turbulent and much of the energy at the drop was dissipated so that it was the depth of flow in the box inlet rather than the box depth itself that determined the proportions of the outlet.

Check Tests

Table 3 is included here to show the tests made to verify the design formulas. These tests were made with the various combinations shown below:

$B/W = 2.0, 1.5, 1.0, 0.5.$

$D/W = 1.0, 0.5, 0.25.$

W_e/W varied from 1 to 3.4.

The straight section varied from the minimum length given by Equation (3) to 3.4 times the minimum.

The stilling basin sidewall flare varied from ∞:9 (parallel sidewalls) to 2:1.

The design equations were used to compute the sidewall height, end and longitudinal sills, and tailwater depth.

The length of the basin was varied from the minimum given by Equation (6) to 2.8 times the minimum.

Results of these check tests showed that no changes were required and that the operation of the outlet was satisfactory.

TABLE 3.--*Check tests*

W = 0.667 ft., wingwall position = 60° from centerline, wingwall top slope = 45° from horizontal, length of run = 4 hours.

Run No.	Q c.f.s.	B ft.	D ft.	d_c ft.	L_s ft.	L_B ft.	Sidewall flare	W_e ft.	d_{ce} ft.	d_2 ft.	c ft.	Sidewall height ft.	Scour Maximum[1] ft.	Scour Distance[2] ft.	Scour Location[3] ft.
358	0.530	0.667	0.333	0.270	0.324	1.00	4:1	1.16	0.187	0.299	0.050	0.400	0.07	0.8	a
359	.810	1.333	.333	.358	1.330	.83	3:1	1.20	.242	.387	.065	.516	.06	.6	b
360	.800	1.333	.667	.355	.390	.83	4:1	1.08	.257	.413	.070	.548	.07	1.0	a
361	.305	.667	.166	.186	.224	1.00	4:1	1.16	.129	.196	.033	.260	.03	.5	a
362	.395	.333	.333	.221	.311	1.60	4:1	1.46	.131	.210	.035	.280	.03	.6	a
363	.530	.667	.333	.270	.324	1.20	3:1	1.46	.160	.257	.043	.344	.08	.7	a
364	.960	1.333	.667	.401	.600	1.87	4:1	1.62	.222	.340	.056	.452	.10	.4	b
365	.810	1.333	.333	.358	.396	.83	3:1	1.20	.242	.387	.065	.516	.05	.6	a
366	.240	.333	.166	.159	.224	1.60	2:1	2.26	.070	.187	.031	.248	.06	.6	a
367	.345	.333	.166	.202	.288	1.50	6:1	1.16	.140	.224	.037	.300	.02	.6	a
368	.240	.333	.166	.159	.224	1.50	3:1	1.66	.087	.172	.028	.228	.06	.7	a
369	.345	.333	.166	.202	.288	1.33	4:1	1.32	.128	.204	.034	.272	.03	.5	a
370	.405	1.333	.166	.225	.247	1.50	3:1	1.66	.123	.197	.033	.264	.07	.2	b
371	.305	.667	.166	.186	.224	1.20	6:1	1.06	.138	.220	.037	.292	.06	.7	a
372	.400	.667	.166	.223	.268	1.40	2:1	2.06	.105	.212	.035	.284	.06	.5	a
373	.328	1.333	.166	.196	.218	1.20	6:1	1.06	.144	.226	.038	.300	.03	.5	a
374	.400	.667	.166	.223	.268	1.20	3:1	1.46	.132	.212	.035	.284	.05	.2	b
375	.405	1.333	.166	.225	.247	.83	4:1	1.08	.164	.262	.044	.348	.02	.4	a
376	.810	1.333	.333	.358	.396	1.60	4:1	1.46	.212	.340	.057	.452	.03	.9	a
377	.690	.667	.333	.321	.387	1.60	6:1	1.13	.226	.362	.060	.484	.07	.8	a
378	.675	1.333	.333	.317	.348	1.60	6:1	1.13	.223	.356	.059	.476	.07	.7	a
379	.690	.667	.333	.321	.387	1.40	4:1	1.36	.200	.322	.053	.428	.03	.4	b
380	.675	1.333	.333	.317	.348	1.20	2:1	1.86	.160	.257	.043	.344	.07	.4	b
381	.395	.333	.333	.221	.311	1.70	6:1	1.23	.147	.237	.039	.316	.07	.6	a
382	.960	1.333	.667	.401	.600	1.87	6:1	1.28	.259	.415	.070	.552	.07	.8	a
383	.860	1.000	.667	.373	.422	2.47	∞:1	.67	.373	.595	.100	.802	.07	.8	a
384	.556	.333	.667	.279	.390	1.60	4:1	1.46	.165	.268	.045	.356	.07	.3	b
385	.800	1.333	.667	.355	.390	1.60	4:1	1.46	.210	.337	.056	.448	.07	.4	b
386	.750	1.000	.667	.340	.390	.88	4:1	1.10	.244	.390	.065	.520	.07	.7	a

Notes: [1]Below floor of stilling basin. [2]From end of stilling basin. [3]Location of maximum scour
a. Near centerline
b. Near wingwall

SUMMARY OF RESULTS

The results of the tests made to develop design rules for a box-inlet spillway outlet are summarized below and in figure 14:

1. The minimum length of the straight section is

$$L_s = d_c\left(\frac{0.2}{B/W} + 1\right). \text{ - - - - - - - - - - - - - } (3)$$

2. A suitable flare from the straight to a maximum of 2:1 may be used.

3. The minimum length of the stilling basin may be computed from the equation

$$L_B = \frac{L}{2B/W}. \text{ - - - - - - - - - - - - - - - - - } (6)$$

A greater length may be used if desired.

4. Where W_e/d_{ce} is less than 11.5, the required tailwater depth is

$$d_2 = 1.6d_{ce}. \text{ - - - - - - - - - - - - - - - - } (5)$$

Where W_e/d_{ce} is greater than 11.5, the equation

$$d_2 = d_{ce} + 0.052W_e \text{ - - - - - - - - - - - - } (4)$$

should be used. Stilling basins having values of W_e/d_{ce} greater than 11.5 are not recommended.

5. The height of the end and longitudinal sills should be

$$c = d_2/6. \text{ - } (7)$$

The width of the sills may be equal to or less than the height.

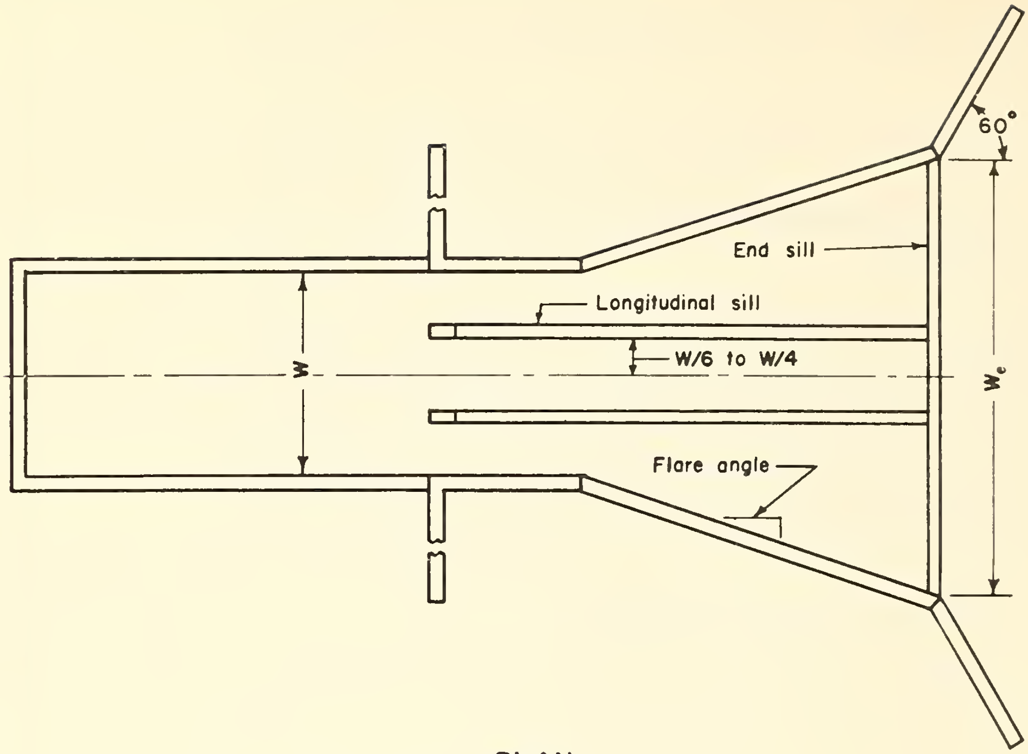
6. When W_e is less than $2.5W$, only two sills are required. These should be placed from $W/6$ to $W/4$ from each side of the centerline. If W_e is greater than $2.5W$, four sills are needed, and they should be placed one-half the distance from the center of the first sills to the sidewall at the end of the basin.

7. The sidewall height should be

$$(4/3)d_2 \text{ - } (8)$$

or greater.

8. The wingwalls should be triangular in shape, have a top slope of 45 degrees, and be set at an angle of 60 degrees from the centerline.



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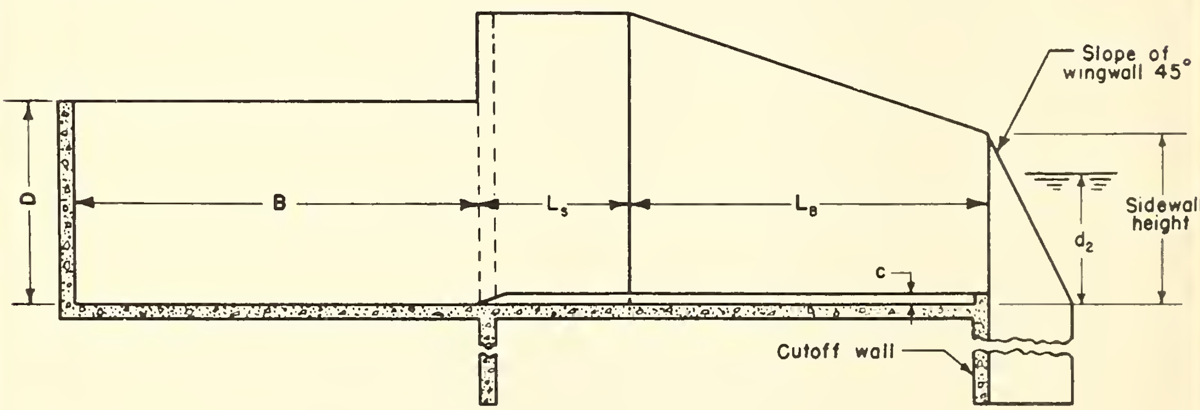

SECTION AT ℄

OUTLET FOR BOX INLET DROP SPILLWAY

GLOSSARY

B	Length of box
c	End and longitudinal sill heights
D	Depth of box
d_c	Critical depth in straight section, $d_c = \sqrt[3]{\dfrac{(Q/W)^2}{g}}$
d_{ce}	Critical depth at end of basin, $d_{ce} = \sqrt[3]{\dfrac{(Q/W_e)^2}{g}}$
d_2	Tailwater depth
g	Acceleration due to gravity
H	Head over crest
L	Crest length, $2B + W$
L_B	Length of flared section of basin
L_s	Length of straight section of basin
Q	Discharge
W	Width of box and straight section
W_e	Width at end of basin
Flare	Longitudinal to transverse